A STATISTICAL MODEL OF ATMOSPHERIC TEMPERATURE SIGNALS

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THESIS

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ATMOSPHERIC TEMPERATURE SIGNALS

by

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A Statistical Model of Atmospheric Temperature Signals

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ABSTRACT

The "ramp" is an often observed feature in temperature fluctuations during unstable atmospheric conditions. It is characterized by a gradual increase in temperature followed by a sudden drop to an ambient level. This ramp clearly distinguishes temperature signals from other turbulence signals such as velocity. Three different ramp-type atmospheric temperature fluctuations and their derivatives are constructed and statistically examined for the parameters skewness and coefficient of excess. These statistical values are compared with values obtained from actual signals. The "complex ramp signal" was found to represent these quite well. Skewness and coefficient of excess for this signal could be altered almost independently of each other. The complex ramp is constructed by inscribing nearly symmetrical consecutive triangles within two envelope rays of constant but different slopes such that the two envelope rays approximate a ramp function.

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I. INTRODUCTION

A. OBJECTIVE

Atmospheric and oceanic turbulence contributes greatly to interactions at the air/sea interface. Mathematical models have been developed which attempt to describe this turbulent boundary layer where atmosphere and ocean meet. As sensing systems become more sophisticated and more turbulence data becomes available, existing models are accordingly modified. An important modification was made by Kolmogorov (1962) and others to account for rather large fluctuations observed in the energy dissipation rate. Such fluctuations were observed primarily in differentiated turbulence signals which emphasized high frequency components. Kolmogorov revised his theory in order to incorporate how the velocity derivative's skewness (s) and coefficient of excess (c.e.) increased with the Reynold's number (Re). In the energy containing region the parameters s and c.e. are zero since the turbulence fluctuations seem to have a Gaussian distribution. At small scales (high frequencies) they are decidedly not zero. The skewness and coefficient of excess of the derivative of the temperature fluctuations are not zero either. One might then ask, "Knowing s and c.e. from real data, is it possible to construct signals that resemble observed temperature signals?" Such was the objective of this thesis.

B. GENERAL FEATURES OF TEMPERATURE SIGNALS

The "ramp" is an often observed feature in temperature fluctuations during unstable atmospheric conditions. It is characterized by a gradual increase in temperature followed by a sudden drop to an ambient level. The signal rarely falls below this ambient level (Figure 1). This sudden drop clearly distinguishes a temperature signal from other turbulence signals such as velocity signals whose main perturbations from the ambient level are usually gradual rises with accompanying gradual descents. It seems natural to conclude that these observable non-Gaussian type features in temperature signals probably contribute to the measureable skewness and coefficient of excess.

Electronic pattern recognition studies of atmospheric temperature fluctuations have been made by Sokol (1971). Although his study was not exhaustive, he achieved over 70% detection success. Another method of describing these signals is statistically through skewness and coefficient of excess. Since these statistics are zero for Gaussian noise, their values would represent only the non-Gaussian character of the signal. Thus, it may be possible in the future to use the frequency and structure of the ramps as a measure of some meteorological conditions.

Kaimal and Businger (1970) and Gill (1971) have demonstrated, over land at least, that the ramps are manifestations of convective plumes present near the air/earth interface. A schematic of the plume and its relation to the ramp, by

Gill (1971), are shown in Figure 2. Taylor (1958) and Gill (1971) have shown that these ramps can be correlated to other ramps appearing simultaneously at different heights but with a slight offset owing to a tilt in the plume; presumably due to wind shear. Boston (1971) indicated that the ramps in the temperature signal often correlate with perturbations in velocity signals. Safley (1972) has related them to water waves and velocity signals.

Plumes form a significant feature in the atmospheric boundary layer. Although they are present only a small fraction of the time they may account for the majority of heat, moisture, and momentum exchange. Safley (1972) found that the plumes accounted for 10% of the signal but 32% of the heat flux. Furthermore, they cause random fluctuations in electromagnetic waves over line-of-sight paths. Of recent interest is the effect they have on laser beams. When beamed over water they exhibit a random walking at the target. This is of considerable importance if a laser beam is to be used in a variety of practical applications, such as fire control systems.

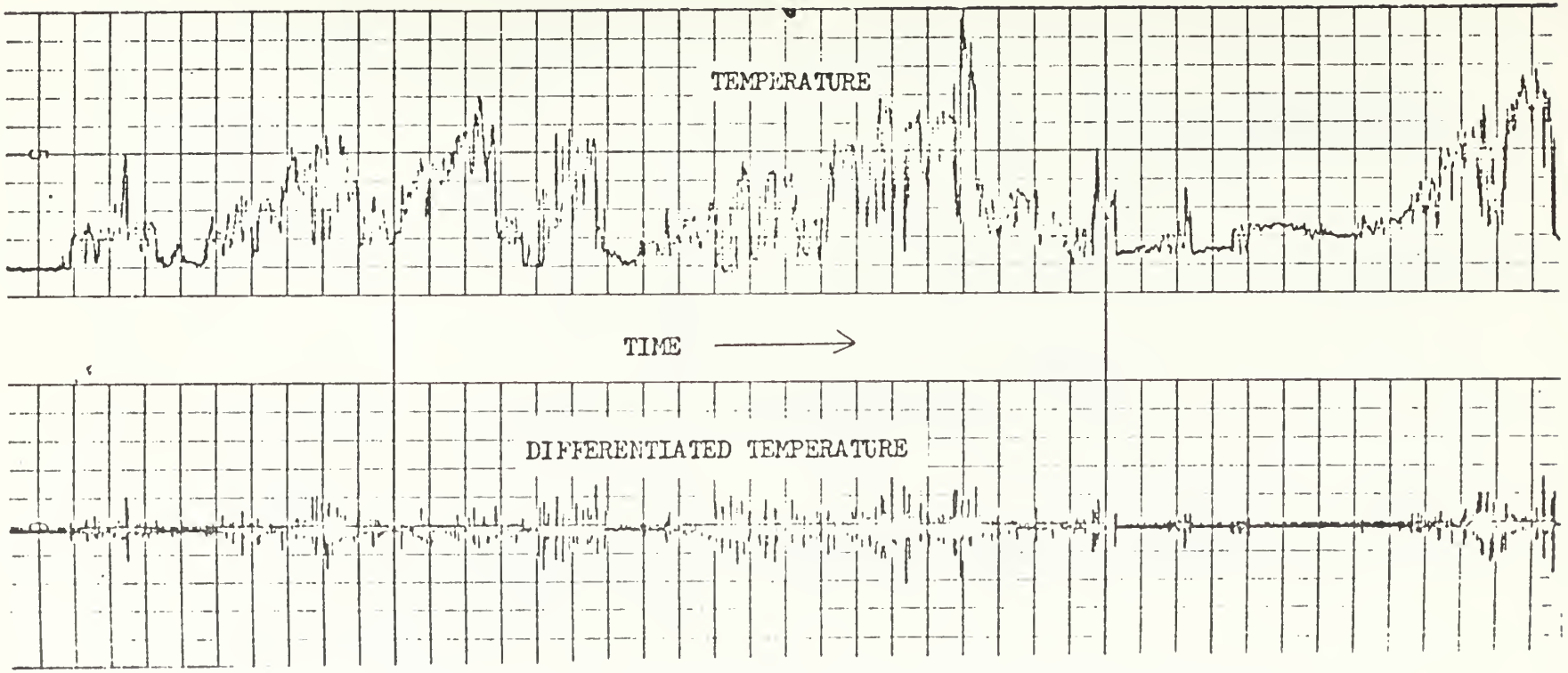

Fig. 1. Atmospheric Temperature and Differentiated Temperature Signal.

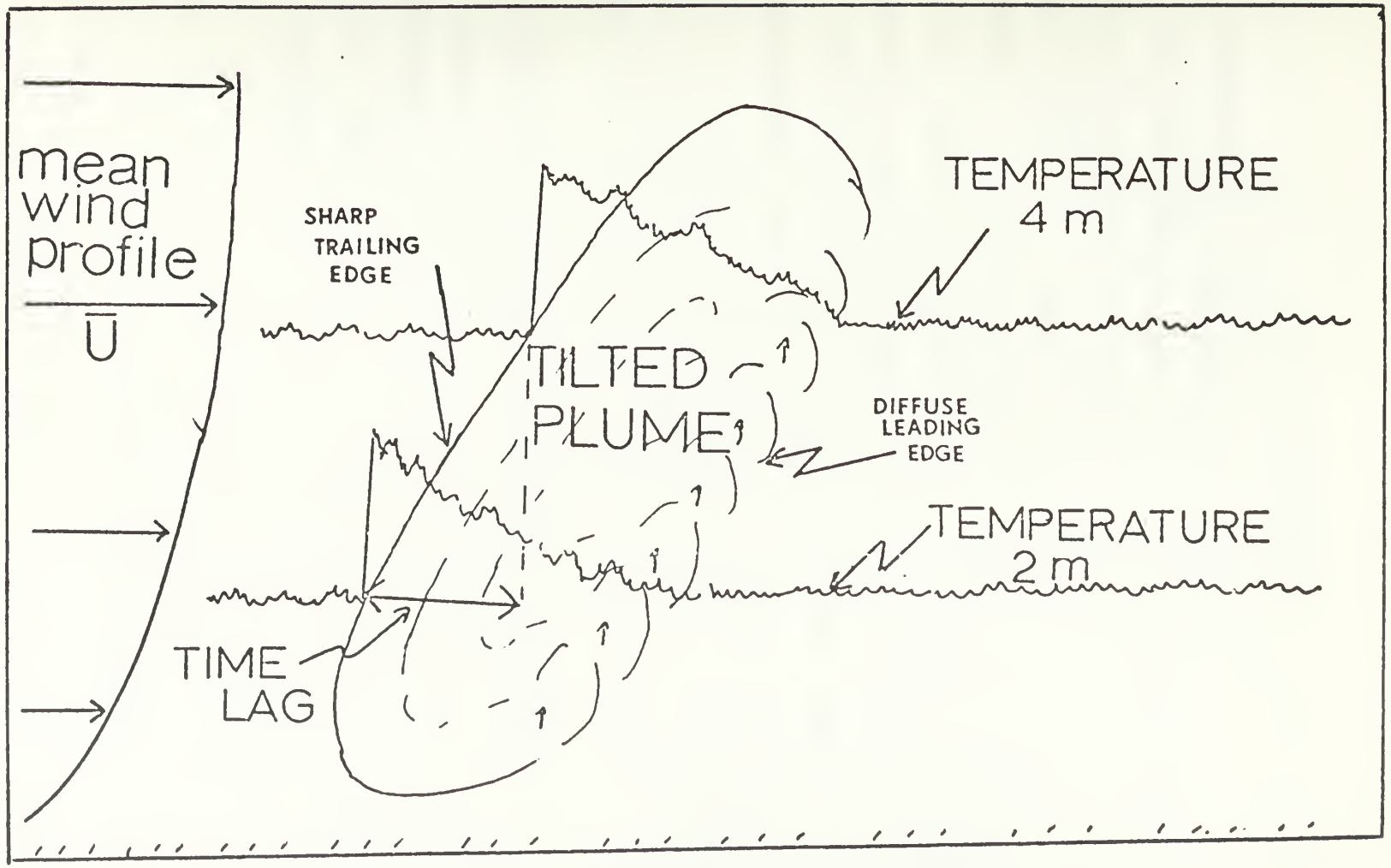

Fig. 2. Schematic of Convective Plume According to Gill (1971).

II. SIGNALS

A. ATMOSPHERIC TEMPERATURE FLUCTUATIONS

When the atmosphere is stable the temperature fluctuations tend to be small because the vertical turbulent velocity component tends to be damped out by the vertical temperature gradient. When the atmosphere is neutral the fluctuations are also small but tend to have both positive and negative excursions due to the lack of restoring buoyant forces.

Unstable conditions, on the other hand, exhibit the characteristic ramp features in the temperature trace (Figure 3). This is the condition that usually exists during the daytime in the lower atmosphere because the earth is heated and warms from below causing upward sensible heat transfer.

B. MODELS OF ATMOSPHERIC TEMPERATURE FLUCTUATIONS

Atmospheric turbulence for stable and neutral conditions is difficult to model since it is a broad band stochastic process. However, because of the characteristic ramp shape of temperature fluctuations in unstable conditions, some attractive possibilities for models present themselves. The model for the temperature signal of unstable conditions will consist of a basically straight line ramp signal to which variations will be added.

Rather than examining spectra of the modeled atmospheric temperature fluctuations, statistics of the derivative of the model will be examined. The differentiated signal emphasizes

the high frequency (high wave number) region of the signal which is the region of most interest in the modeling process since measurements in the last decade clearly indicate that the high wave number region is decidedly non-Gaussian. Also, visual inspection of ramps indicates that high frequency fluctuations may be important in ramp structures.

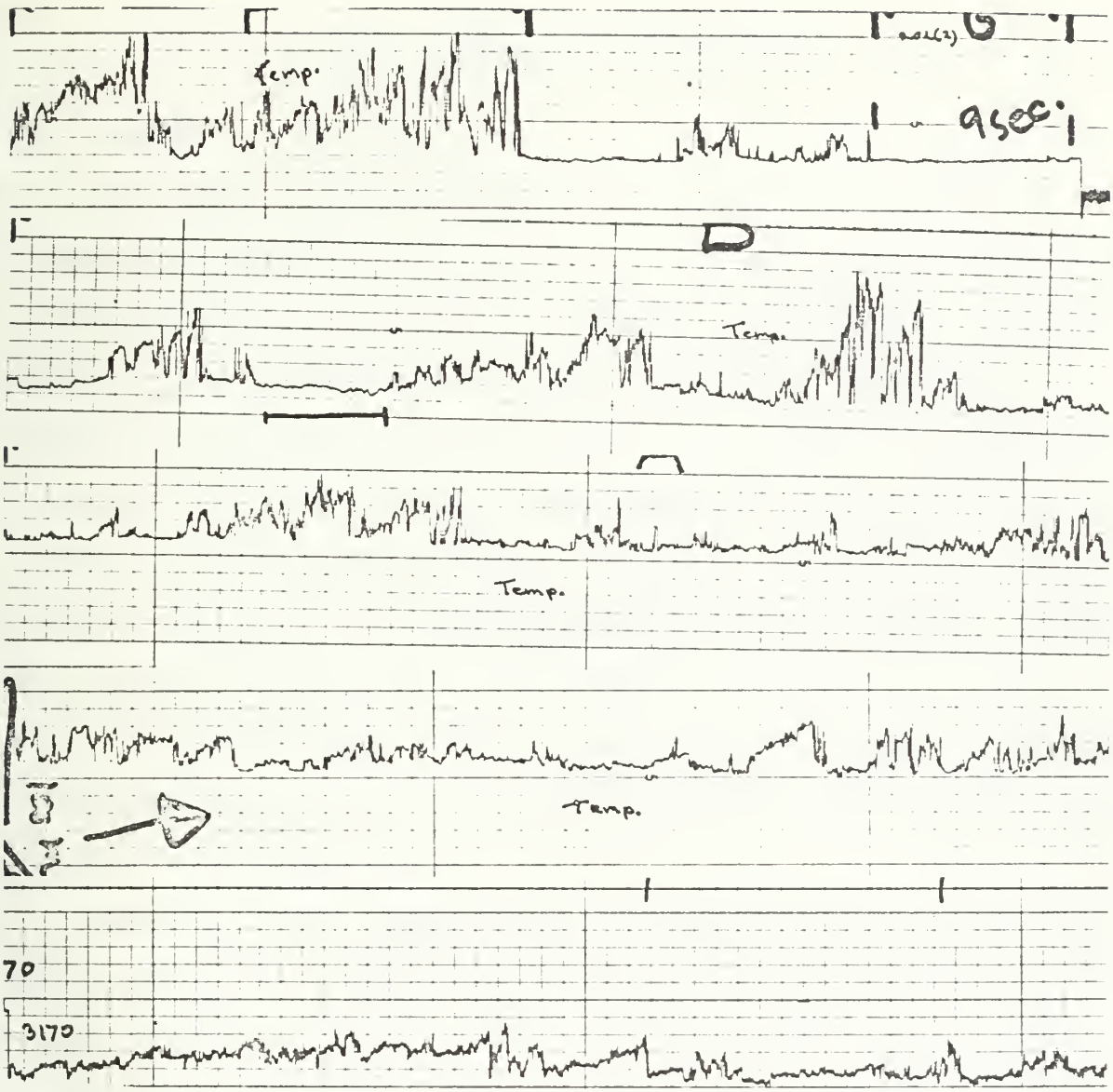

FIGURE 3. Growth of Ramps as Atmosphere Changes from Stable to Unstable (Bottom to Top).

III. METHOD OF EXAMINATION

A. SIGNAL

The signal modeling was done on an IBM 360/67 digital computer at the W. R. Church Computer Center, Naval Postgraduate School, Monterey, California. The basic ingredient in each model is the individual ramp which will be repeated at a specified interval. This collection of repetitive ramps will comprise the model signal. Each signal will be stored in a 10,000 X 1 vector array which represents the time axis of the signal. The size of the array may be varied, however, since the models are periodic. The distance between each array entry is constant and equal to the distance between samples of a digital recorder or converter (which is a function of the original sampling rate).

The models are dimensionless although voltage is implied and terms such as period and width must be redefined as they refer to digital words. Width refers to consecutive digital words or array entries and is used to describe the length of a ramp or a ramp component. Ramp period is the number of consecutive digital words between the start of a ramp and the start of the next succeeding ramp.

Three ramp modifications of increasing complexity will be examined as possible models for the temperature signal. The first is a "standard ramp signal" whose ramps are constructed of a gradual rise ending in a vertical drop (Figure 4) as

described by Gibson et al (1971). The variable parameters of this signal are (1) the period of the ramp, (2) the slope of the ramp, and (3) the width of the ramp.

The second modification is an "asymmetrical ramp" with a gradual rising front slope followed by a short steep back slope (Figure 5). The variables in this signal are (1) ramp period, (2) the back slope of the ramp, (3) ramp width, and (4) the width of the back slope. The front slope value and amplitude need not be included since they are functions of the other variables. Specifically,

front slope = ((back slope width) X (back slope))/ ((ramp width) - (back slope width)), amplitude = (back slope) (back slope width).

The third modification, a "complex ramp", is constructed by inscribing nearly symmetrical consecutive triangles (teepees) within two envelope rays of constant but different slopes such that the two rays approximate a ramp function (Figure 6). Each succeeding slope of the inscribed teepees will be greater in absolute value and alternate in sign. This type of model is chosen because close inspection of temperature strip charts shows that large fluctuations of increasing amplitude is a commonly observed ramp feature. The variables for this signal are (1) ramp period, (2) slope of the upper defining ray, (3) slope of the lower defining ray, and (4) the width of the ramp. The period of the internal teepees is not listed as a variable because, as will be explained later, the model

is dimensionless and, for example, halving the period or doubling the frequency of the internal teepees can be accomplished by simultaneously doubling the ramp period and ramp width.

B. DIFFERENTIATED SIGNAL

As previously mentioned the differentiated signal will be examined since it emphasizes the higher frequencies that contribute to the non-Gaussian nature of the signals. Therefore, now that the direct signal has been modeled the differentiated signal must be computed. The differentiated standard ramp signal is merely a box function whose amplitude is equal to the slope of the ramp (Figure 4).

The differentiated asymmetrical ramp signal is an alternating asymmetrical box function. Each differentiated pulse consists of a broad positive box whose amplitude is equal to the front slope of the ramp followed by a short, highly negative box whose amplitude is equal to the back slope of the ramp (Figure 5).

The signal model for the derivative of the complex ramp (Figure 6) is constructed by letting

$\frac{dy}{dx}$ = uslope (1), the slope of the uppermost limiting ray and,

$\frac{dy'}{dx'}$ = lslope (2), the slope of the lowermost limiting ray.

For representation on a digital computer the implied distance between successive array entries is a mesh length. Then within the ramps each succeeding array entry represents successive slopes of the inscribed teepees. However, for purposes of computing these slopes the mesh length is offset by half its

length and the difference between successive intersections of the upper slope and the lower slope is computed. From equations (1) and (2),

$$dy = (dx)(uslope)$$

$$dy' = (dx')(lslope).$$

Let $n = dx_n$, where n is the number of mesh lengths along the time axis of the signal measured from the start of the ramp. Hence,

$$dy_n = n(uslope)$$

$$dy'n = n(lslope).$$

Therefore, assuming the first slope is positive:

$$x(n) = (n+1)\,(uslope) - (n)\,(lslope)$$

$$x(n+1) = (n+2)\,(lslope) - (n+1)\,(uslope)$$

$$x(n+2) = (n+3)\,(uslope) - (n+2)\,(lslope)$$

$$x(n+3) = (n+4)\,(lslope) - (n+3)\,(uslope)$$

$$x(n+4) = (n+5)\,(uslope) - (n+4)\,(uslope)$$

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.
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Note that the first and last values may have to be computed separately since the signal must be continuous with the ambient level at the beginning and end of the ramp. A sample program with this representation is given in a separate section.

C. STATISTICS APPLIED

One can usually discern a temperature signal from a velocity signal by the ramp. However, if the spectra of these signals are examined in the range of about 1 Hz to 1000 Hz they are

remarkably similar, although their statistics such as skewness and coefficient of excess are quite different. As a result, recent turbulence literature has used these two parameters extensively to describe turbulence signals. Therefore, skewness and coefficient of excess will be used as modeling parameters. The skewness and c.e. of the models will be compared to those of actual signals.

Skewness is a measure of the amount a signal differs from its mean value. The skewness of a Gaussian signal is zero. A distribution that is skewed to the right has a positive skewness and a distribution that is skewed to the left has a negative skewness. A symmetrical signal will have zero skewness and a signal with a high skewness value will have pulses that are very asymmetrical. Coefficient of excess is a measure of the peakedness of a distribution. A distribution that is less peaked than normal distribution has c.e. values less than zero, and vice versa. The c.e. of a signal is highly sensitive to infrequent deviations from the mean signal value. Therefore, a signal with ramps spaced relatively far apart will have a higher c.e. value than a signal with ramps spaced close together. These higher order statistics emphasize the higher frequencies which are non-Gaussian. However, since they are exponential functions, they require a longer record to achieve stable results. Therefore, the use of statistics of orders higher than c.e. is somewhat limited.

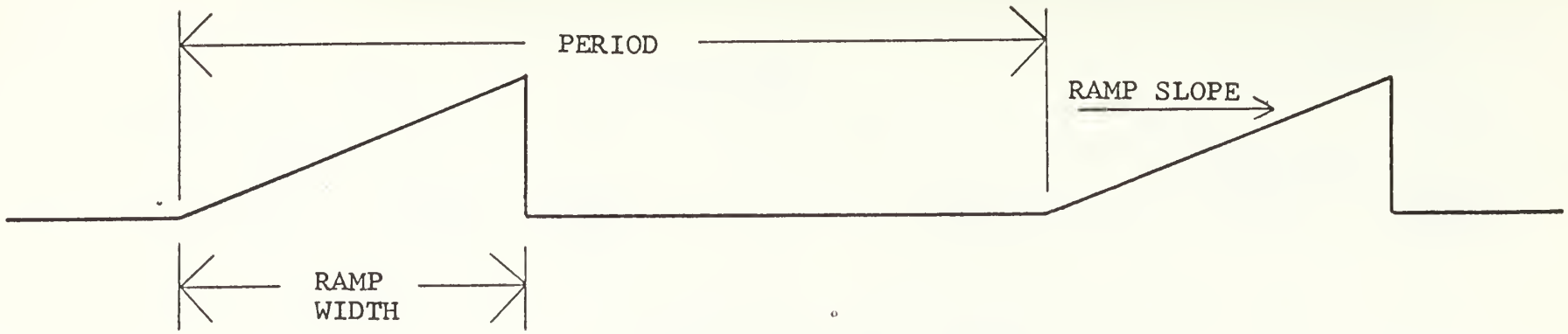
Skewness (s) is defined as :

$s = e^3/(e^2)^{3/2}$, where e is the variation of the signal from its mean value.

Coefficient of excess (c.e.) is defined as:

$$\text{c.e.} = \frac{e^4}{(e^2)^2} - 3.$$ Often one sees $e^4/(e^2)^2$, the ratio of the fourth moment to the second moment, used as a statistic and referred to as "kurtosis," but c.e. will be used here because it is zero for a Gaussian signal.

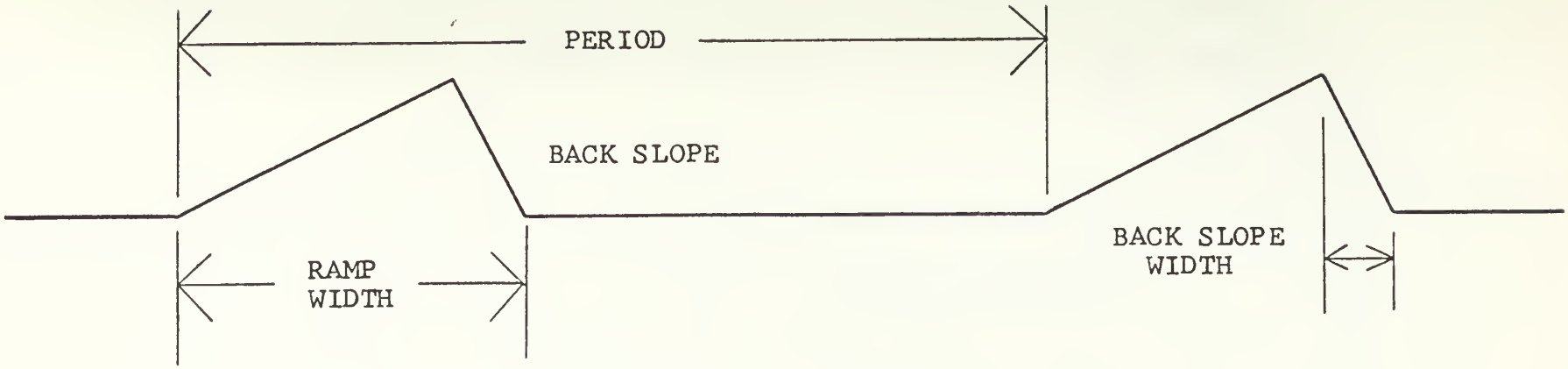
The skewness and c.e. for differentiated temperature signals have been computed by several people (Table I). Although the one thing the statistics seem to have in common is their variability, representative figures can be chosen. For temperature signal a skewness value between 0.2 and 0.5 seems common and likewise a value for c.e. is about 30. Compare these values to representative velocity signal values of -0.5 and 15 for s and c.e. respectively.



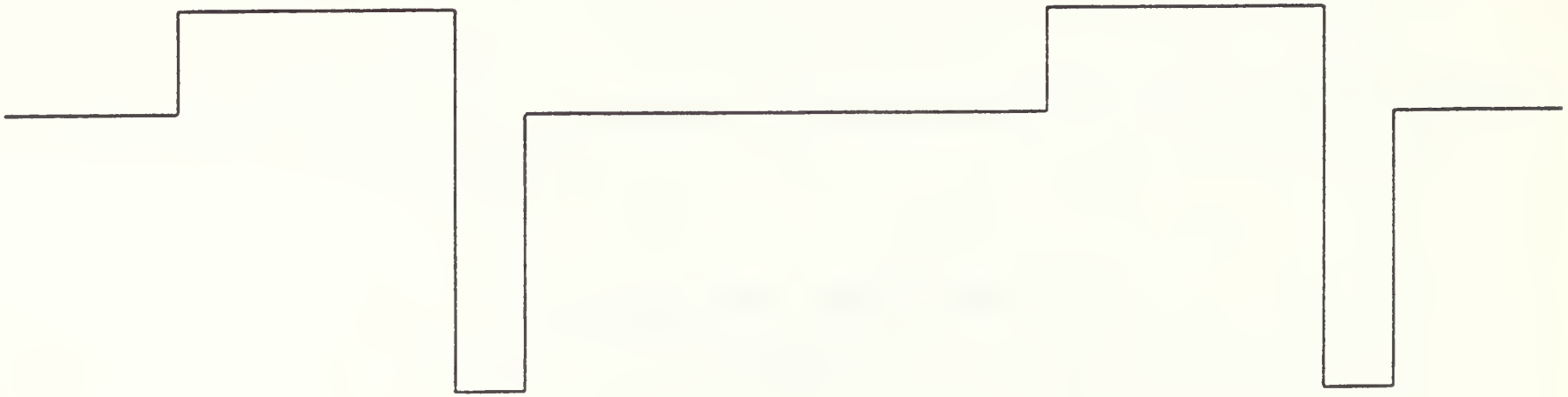
STANDARD RAMP SIGNAL

DIFFERENTIATED STANDARD RAMP SIGNAL

FIGURE 4.

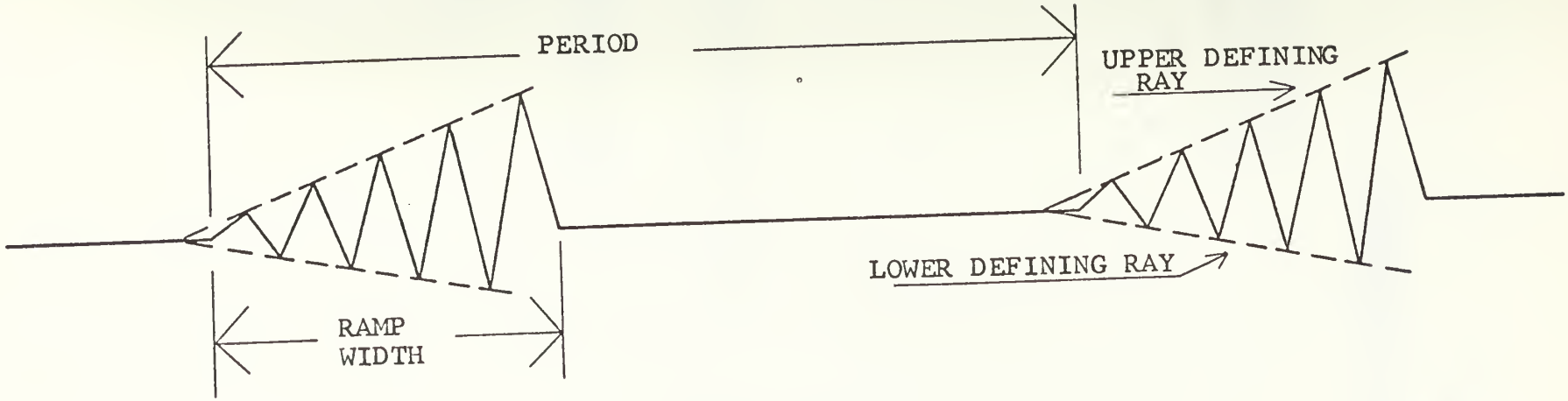


ASYMMETRICAL RAMP SIGNAL



DIFFERENTIATED ASYMMETRICAL RAMP SIGNAL

FIGURE 5.



COMPLEX RAMP SIGNAL

DIFFERENTIATED COMPLEX RAMP SIGNAL

FIGURE 6.

TABLE I.

SKEWNESS AND COEFFICIENT OF EXCESS OF
DIFFERENTIATED TEMPERATURE SIGNALS

INVESTIGATOR	SKEWNESS	C.E.
BOSTON (1971)	-0.013	20.3
	0.195	17.1
	0.140	21.4
	0.002	22.6
	-0.082	13.6
	0.596	22.8
	0.203	12.2
	0.307	13.4
	0.315	32.0
	0.171	13.9
	0.673	30.7
	0.039	15.5
	0.286	18.1
	0.251	11.0
	0.257	12.3
	0.051	6.0
GIBSON et. al. (1970)	0.40	40
	0.72	35
	0.48	34
	0.72	22
GURVICH (1967)		15 - 1400!

IV. RESULTS

The standard ramp signal proved to be a poor representation of the temperature signal. For an appropriate c.e. the skewness was positive but much too large; about five. This agrees with the results obtained by Gibson et.al.(1971) from a similar model. The asymmetrical ramp was no improvement. With this signal a large positive c.e. was accompanied by a large negative skewness. This signal proved to be of some value apart from its intended use and is discussed in Section VI.

The complex ramp signal showed more favorable results. Not only can compatible skewness and c.e. be found but the signal can be adjusted so that skewness and c.e. vary almost independently. A more detailed analysis of the individual signals follows. It should be kept in mind that while a direct signal model is the final product, the different model theories were tested by the statistics of the differentiated signal. Therefore, the following results apply to the statistics of the differentiated signal.

TABLE II.

VARIATION OF DIFFERENTIATED RAMP SIGNAL
WITH PERIOD (FIGURE 7)

PERIOD	RAMP SLOPE	RAMP WIDTH	S.	C.E.
10			0.408	-1.83
20			1.45	0.250
30			2.15	2.65
40	2.0	4.0	2.63	4.90
80			3.98	13.8
100			4.70	20.0
200			6.48	40.0
400			8.49	70.0

Note here that skewness and c.e. both increase with increasing period but they never simultaneously achieve the correct values required by the models.

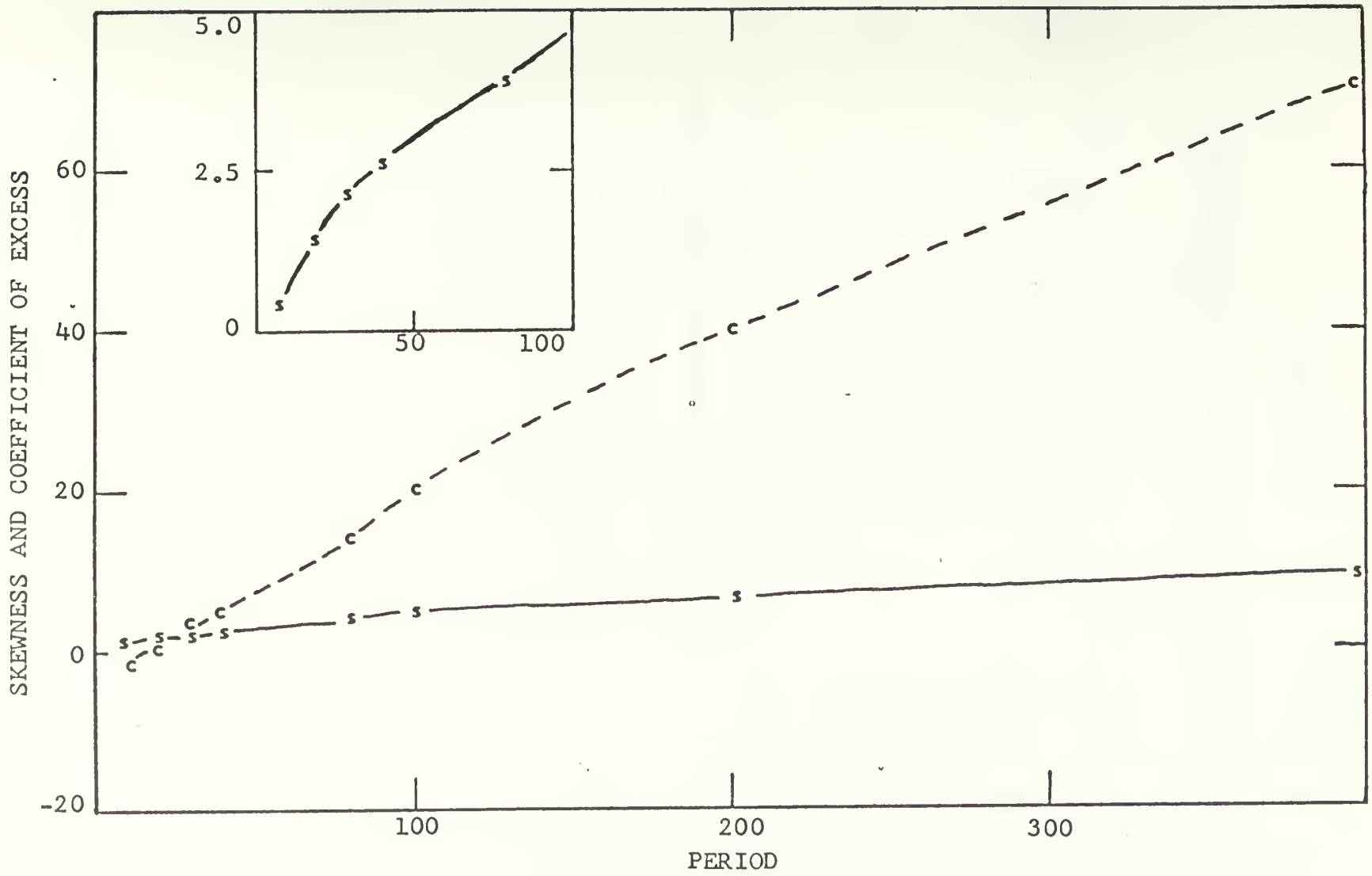


FIGURE 7. Variation of Standard Ramp Signal with Period
(Ramp Slope = 2.0, Ramp Width = 4.0)

TABLE III.

VARIATION OF DIFFERENTIATED RAMP SIGNAL
WITH RAMP SLOPE (FIGURE 9)

PERIOD	RAMP SLOPE	RAMP WIDTH	S.	C.E.
	0.1		2.67	5.12
	0.5		2.67	5.12
40	1.0	4.0	2.67	5.12
	5.0		2.67	5.12

S. and c.e. are independent of ramp slope.

TABLE IV.

VARIATION OF DIFFERENTIATED RAMP SIGNAL
WITH RAMP WIDTH (FIGURE 8)

PERIOD	RAMP SLOPE	RAMP WIDTH	S.	C.E.
		2.0	4.13	15.1
		3.0	3.23	8.41
40	2.0	4.0	2.67	5.11
		5.0	2.27	3.14
		6.0	1.96	1.85
		7.0	1.71	0.929

Here the results are similar to those obtained with a varying period. Although values of s and c.e. can be achieved with the standard ramp signal that are respectively commensurate with measured values from actual signals, the values of s and c.e. are not simultaneously compatible with measured signals and hence this signal is discarded as an appropriate model.

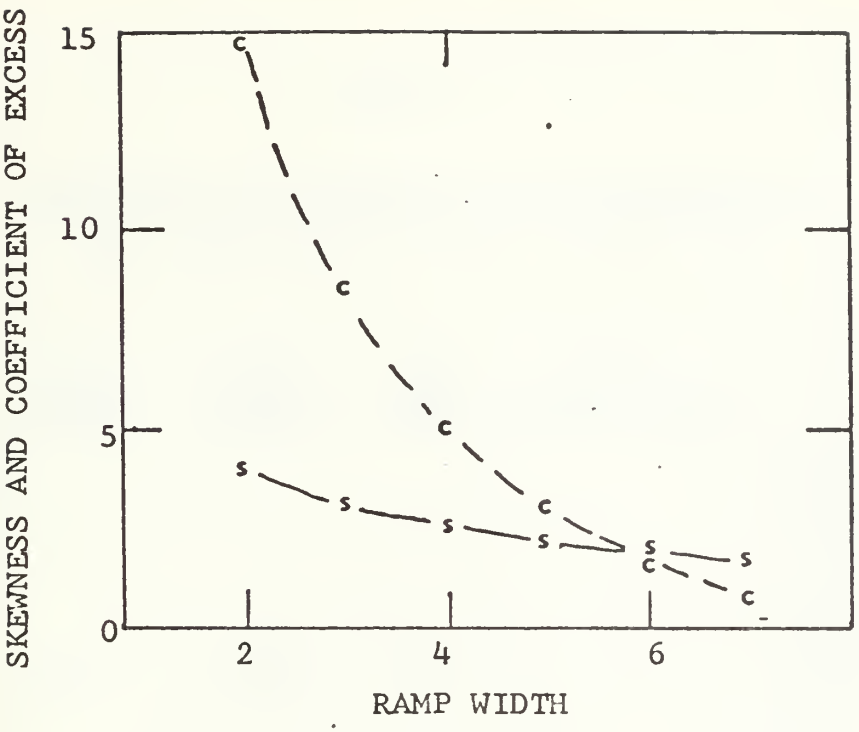


FIGURE 8. Variation of Standard Ramp Signal with Ramp Width (Period = 40, Ramp Slope = 2.0)

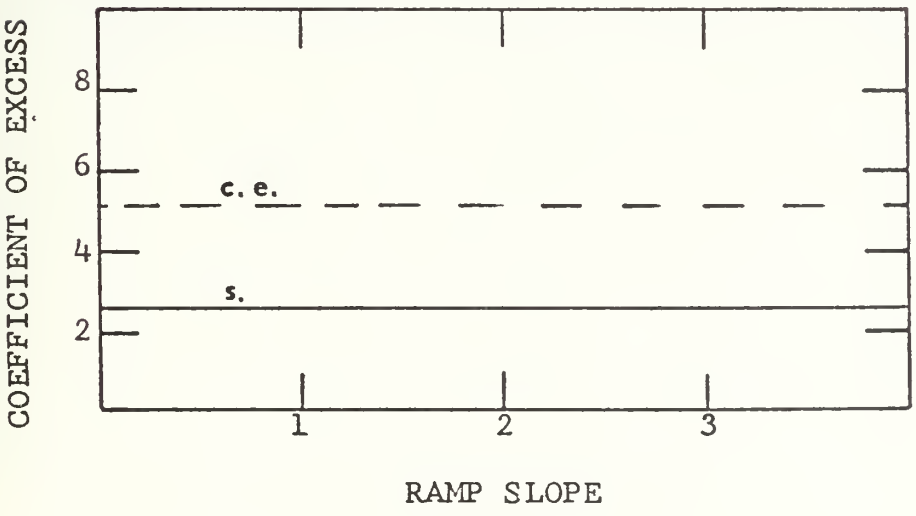


FIGURE 9. Variation of Standard Ramp Signal with Ramp Slope (Period = 40, Ramp Width = 4.0)

TABLE V.

VARIATION OF DIFFERENTIATED ASYMMETRICAL RAMP SIGNAL WITH PERIOD (FIGURE 10)

PERIOD	BACK SLOPE	FRONT SLOPE	RAMP WIDTH	BACK SLOPE WIDTH	S.	C.E.
10					-3.77	13.2
30					-4.64	21.6
50					-6.00	38.0
100	-1.5	0.167	10	1	-8.48	78.9
300					-14.7	243
500					-18.9	403

Although c.e. values are achieved that agree with actual signal values, the skewness values are not only too large in absolute value but negative instead of the small positive values desired.

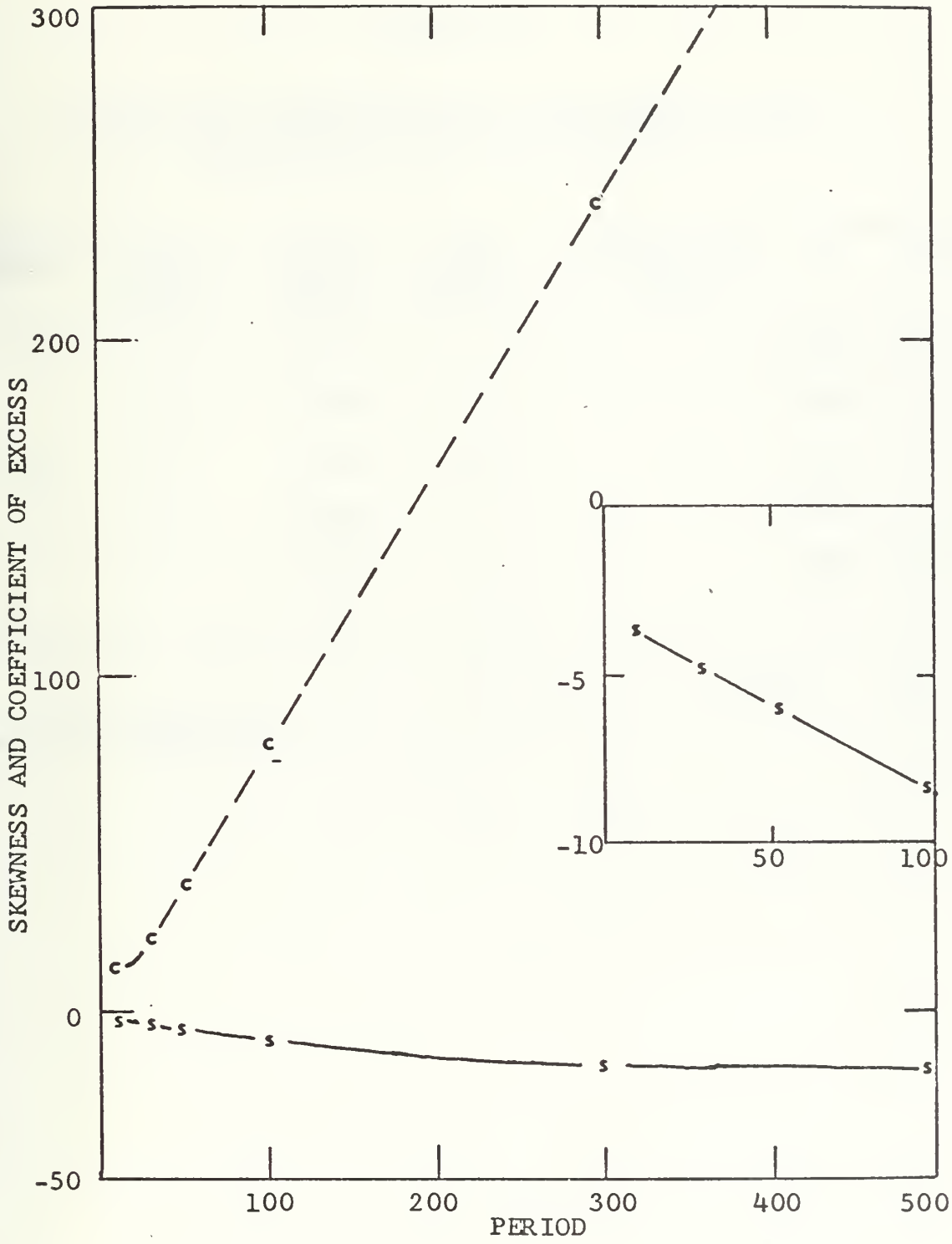


FIGURE 10. Variation of Asymmetrical Ramp Signal with Period
(Back Slope = -1.5, Ramp Width = 10, Back Slope Width = 1)

TABLE VI.

VARIATION OF DIFFERENTIATED ASYMMETRICAL RAMP SIGNAL WITH BACK SLOPE (FIGURE 12)

PERIOD	BACK SLOPE	FRONT SLOPE	RAMP WIDTH	BACK SLOPE WIDTH	S.	C.E.
	-0.10	0.011			-8.43	78.1
	-0.50	0.056			-8.43	78.1
100	-1.0	0.10	10	1	-8.43	78.1
	-1.5	0.144			-8.43	78.1
	-1.9	0.189			-8.43	78.1

Once again the slope of the signal has no effect on the modeling statistics.

TABLE VII.

VARIATION OF DIFFERENTIATED ASYMMETRICAL RAMP SIGNAL WITH RAMP WIDTH (FIGURE 11)

PERIOD	BACK SLOPE	FRONT SLOPE	RAMP WIDTH	BACK SLOPE WIDTH	S.	C.E.
		0.30	6		-7.30	67.0
		0.25	7		-7.72	70.8
		0.21	8		-8.02	73.8
100	-1.5	0.19	9	1	-8.25	76.2
		0.17	10		-8.43	78.1
		0.08	20		-9.23	87.3
		0.05	30		-9.49	90.4

These statistics are not compatible with measured values. The skewness is too large in absolute value and negative in sign.

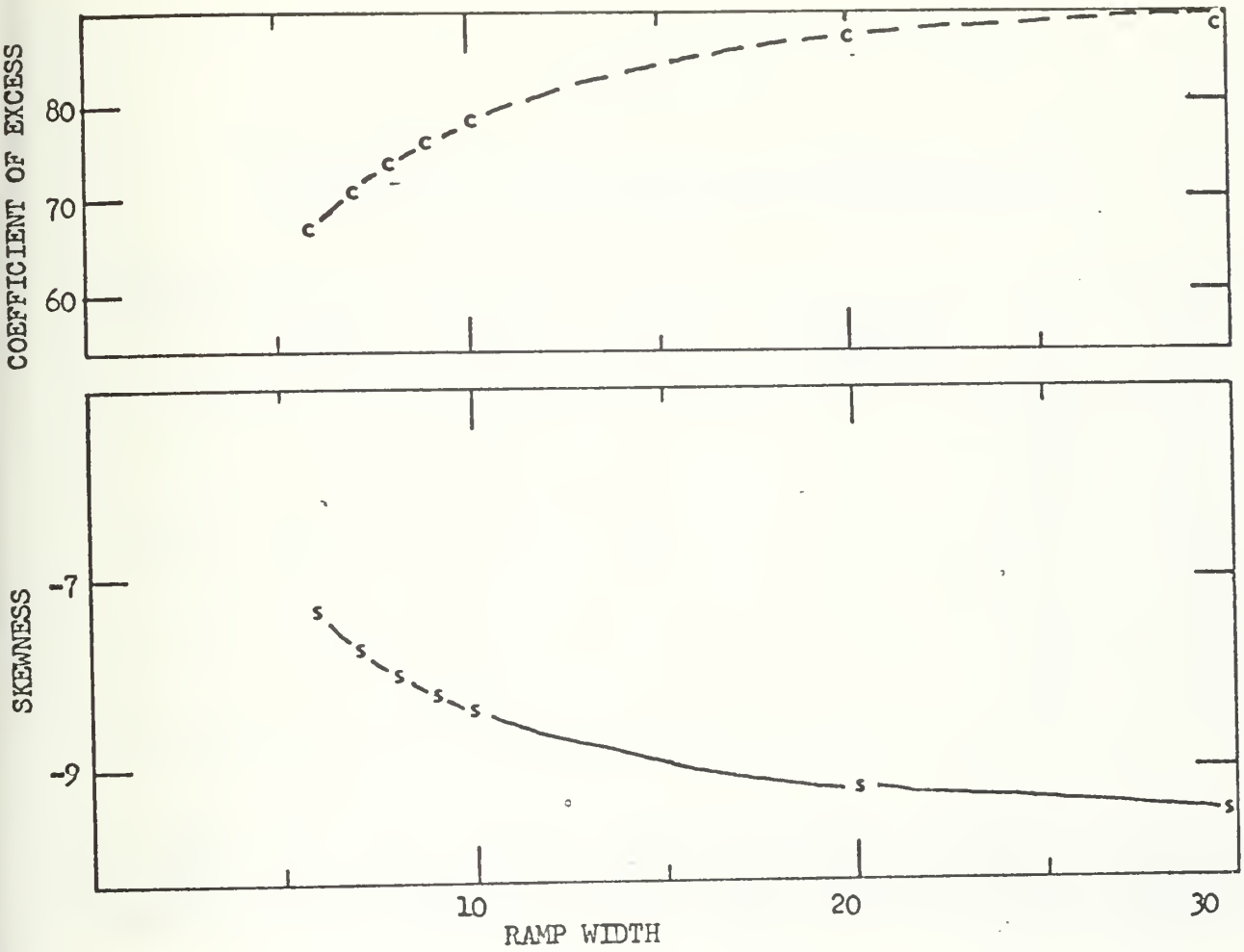


FIGURE 11: VARIATION OF ASYMMETRICAL RAMP SIGNAL WITH RAMP WIDTH
(PERIOD = 100, BACK SLOPE =-1.5, BACK SLOPE WIDTH = 1)

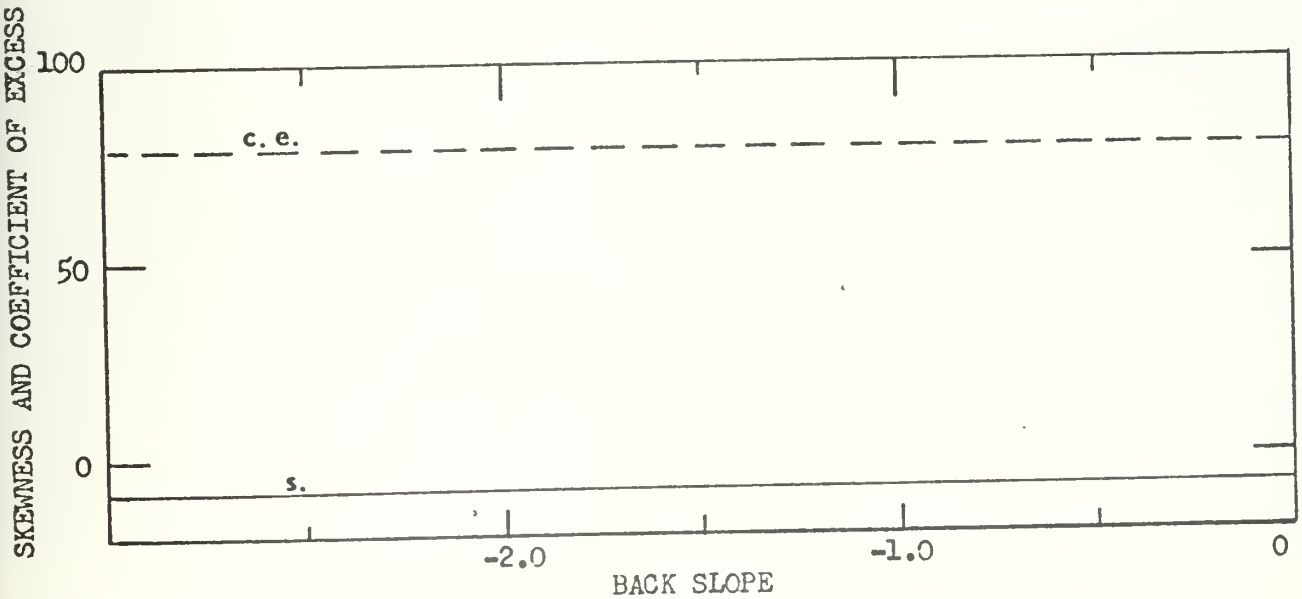


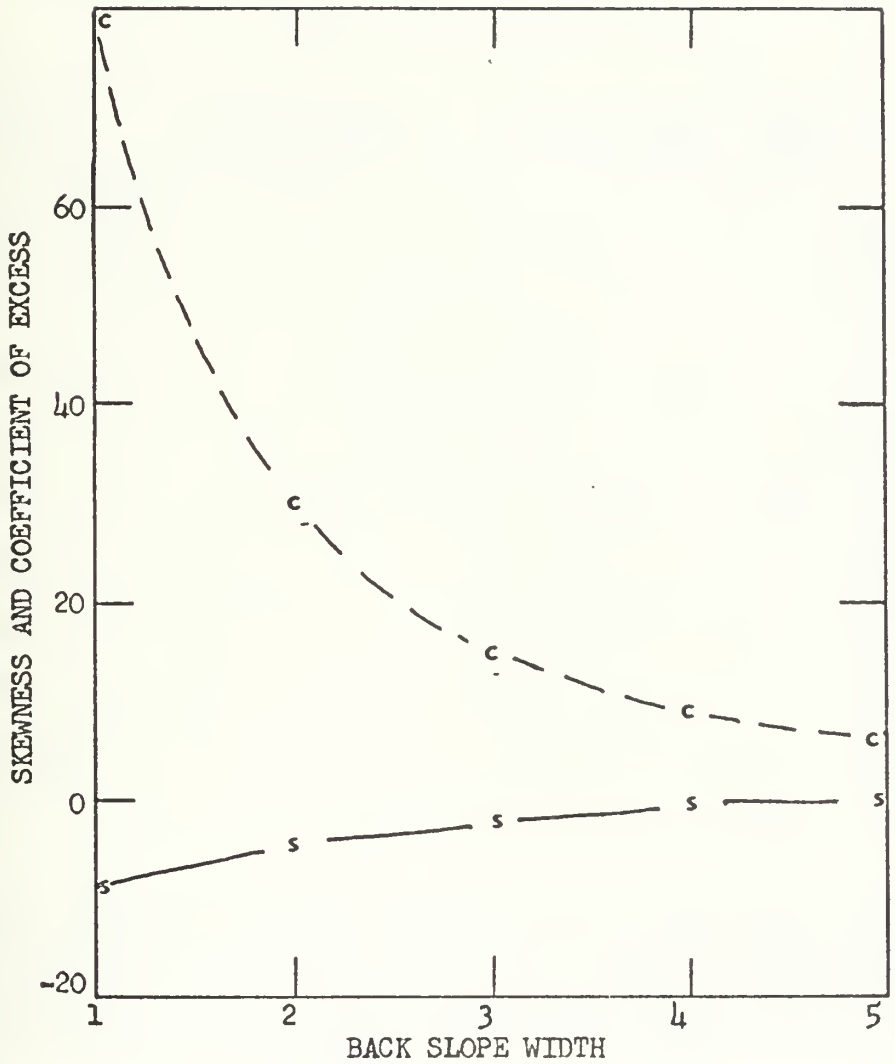
FIGURE 12: VARIATION OF ASYMMETRICAL RAMP SIGNAL WITH BACK SLOPE
(PERIOD = 100, RAMP WIDTH = 10, BACK SLOPE WIDTH = 1)

TABLE VIII.

VARIATION OF DIFFERENTIATED ASYMMETRICAL RAMP SIGNAL WITH BACK SLOPE WIDTH (FIGURE 13)

PERIOD	BACK SLOPE	FRONT SLOPE	RAMP WIDTH	BACK SLOPE WIDTH	S.	C.E.
		0.167		1	-8.48	78.9
		0.375		2	-4.77	29.8
100	-1.5	0.643	10	3	-2.77	14.8
		1.0		4	-1.30	8.78
		1.5		5	0.0	7.0

Note that the skewness finally becomes non-negative (zero) but the c.e. is too low and the shape of the signal is that of a teepee, not a ramp. Therefore, due to the negative skewness inherent in this signal, it is discarded as a possible model.



VARIATION OF ASYMMETRICAL RAMP SIGNAL WITH BACK SLOPE WIDTH
(PERIOD = 100, BACK SLOPE = -1.5, RAMP WIDTH = 10)

FIGURE 13.

TABLE IX.

VARIATION OF DIFFERENTIATED COMPLEX RAMP SIGNAL WITH PERIOD (FIGURE 14)

PERIOD	UPPER BASIC SLOPE	LOWER BASIC SLOPE	RAMP WIDTH	S.	C.E.
40				0.046	-1.27
80				0.064	0.459
100				0.072	1.32
200				0.102	5.64
300	0.8	-0.4	40	0.124	9.71
400				0.145	14.3
600				0.175	22.4
800				0.201	30.2
1000				0.229	40.2

This signal closely approximates actual measured values for periods in the range of 800 to 1000. This appears to be an excellent model for typical atmospheric temperature signals during unstable conditions. Now the effect of the remaining parameters will be examined.

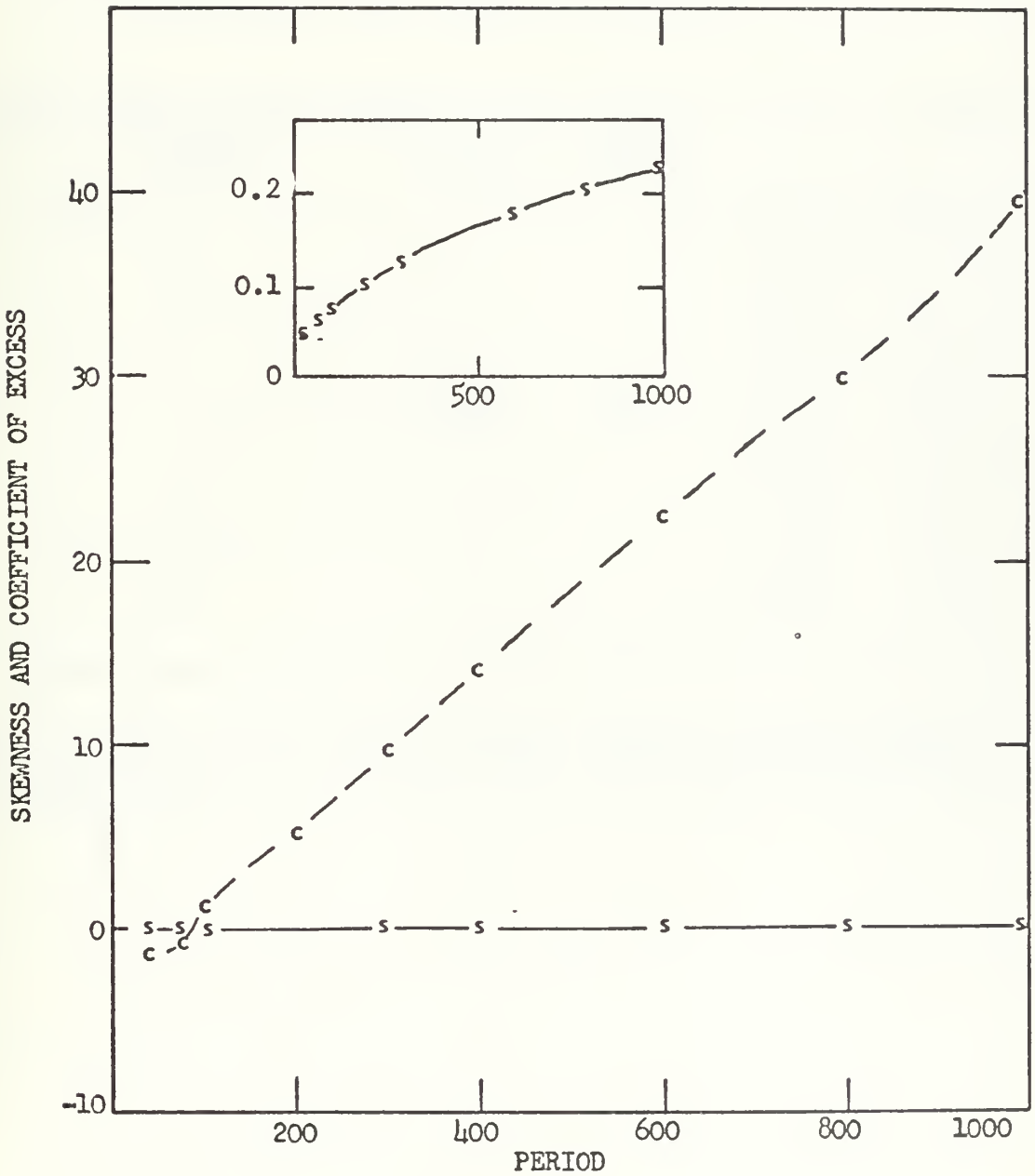


FIGURE 14: VARIATION OF COMPLEX RAMP SIGNAL WITH PERIOD
(UPPER BASIC SLOPE = 0.8, LOWER BASIC SLOPE = -0.4, RAMP WIDTH = 10)

TABLE X.

VARIATION OF DIFFERENTIATED COMPLEX RAMP SIGNAL WITH UPPER BASIC SLOPE (FIGURE 15)

PERIOD	UPPER BASIC SLOPE	LOWER BASIC SLOPE	RAMP WIDTH	S.	C.E.
	0.4			0.208	30.6
	0.8			0.201	30.2
	1.2			0.175	30.2
800	1.6	-0.4	40	0.153	30.2
	2.0			0.134	30.2
	2.4			0.119	30.2
	50			0.008	30.7

The coefficient of excess remains almost constant while the skewness ranges over values not unlike those encountered in real signals.

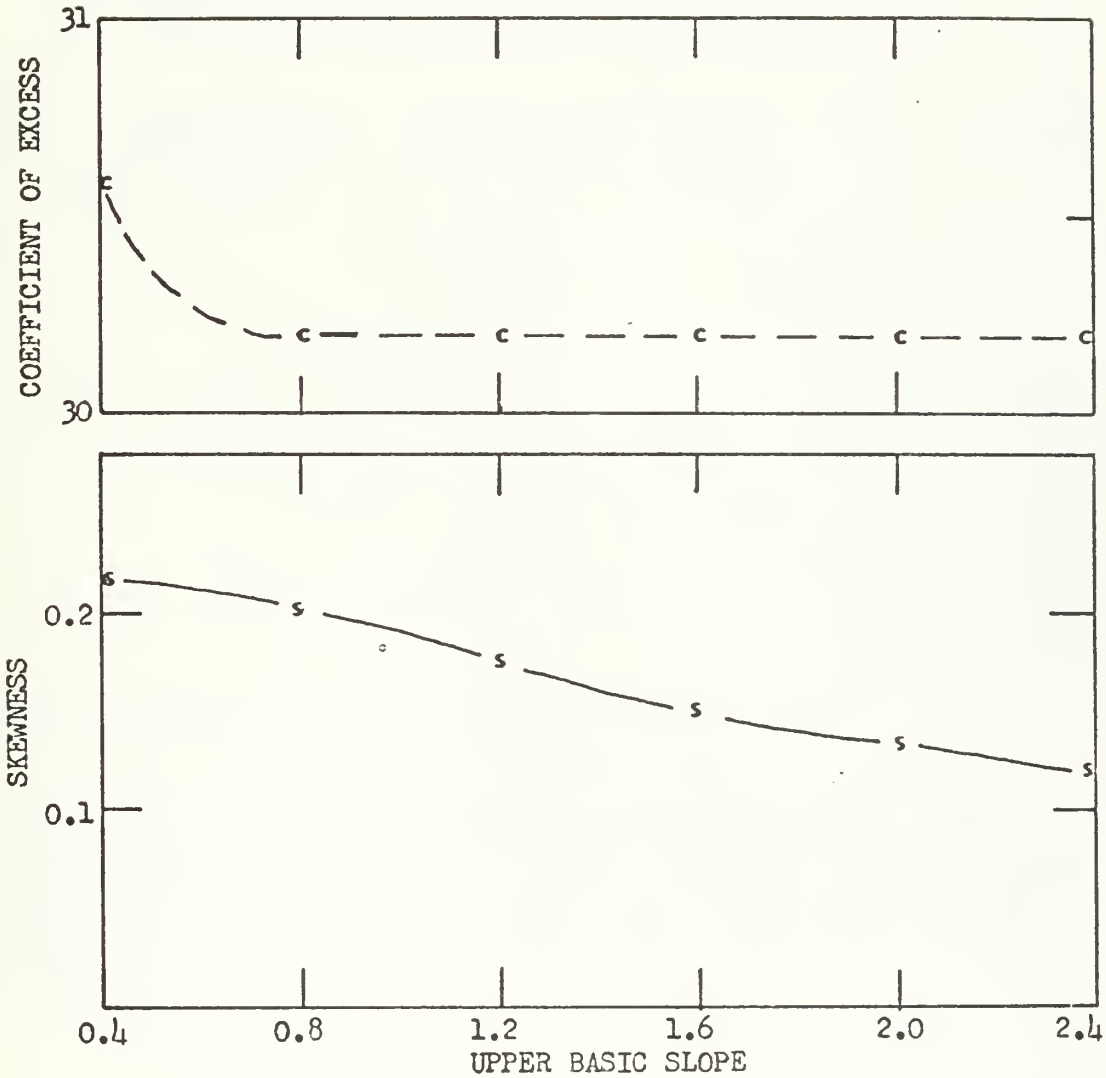


FIGURE 15: VARIATION OF COMPLEX RAMP SIGNAL WITH UPPER BASIC SLOPE (PERIOD = 800, LOWER BASIC SLOPE = -0.4, RAMP WIDTH = 40)

TABLE XI.

VARIATION OF DIFFERENTIATED COMPLEX RAMP SIGNAL WITH LOWER BASIC SLOPE (FIGURE 16)

PERIOD	UPPER BASIC SLOPE	LOWER BASIC SLOPE	RAMP WIDTH	S.	C.E.
		0.6		-10.3	227
		0.4		- 2.29	58.2
		0.2		- 0.488	34.6
800	0.8	0.0	40	0.0	30.7
		-0.2		0.153	30.2
		-0.4		0.201	30.2
		-0.6		0.211	30.4

The values of s and c.e. obtained when the lower basic slope is positive fluctuate greatly but when the lower basic slope becomes negative the c.e. becomes almost constant, about 30, and the skewness stabilizes near 0.2. Therefore, it is concluded that the model of a temperature signal has a lower basic slope less than zero.

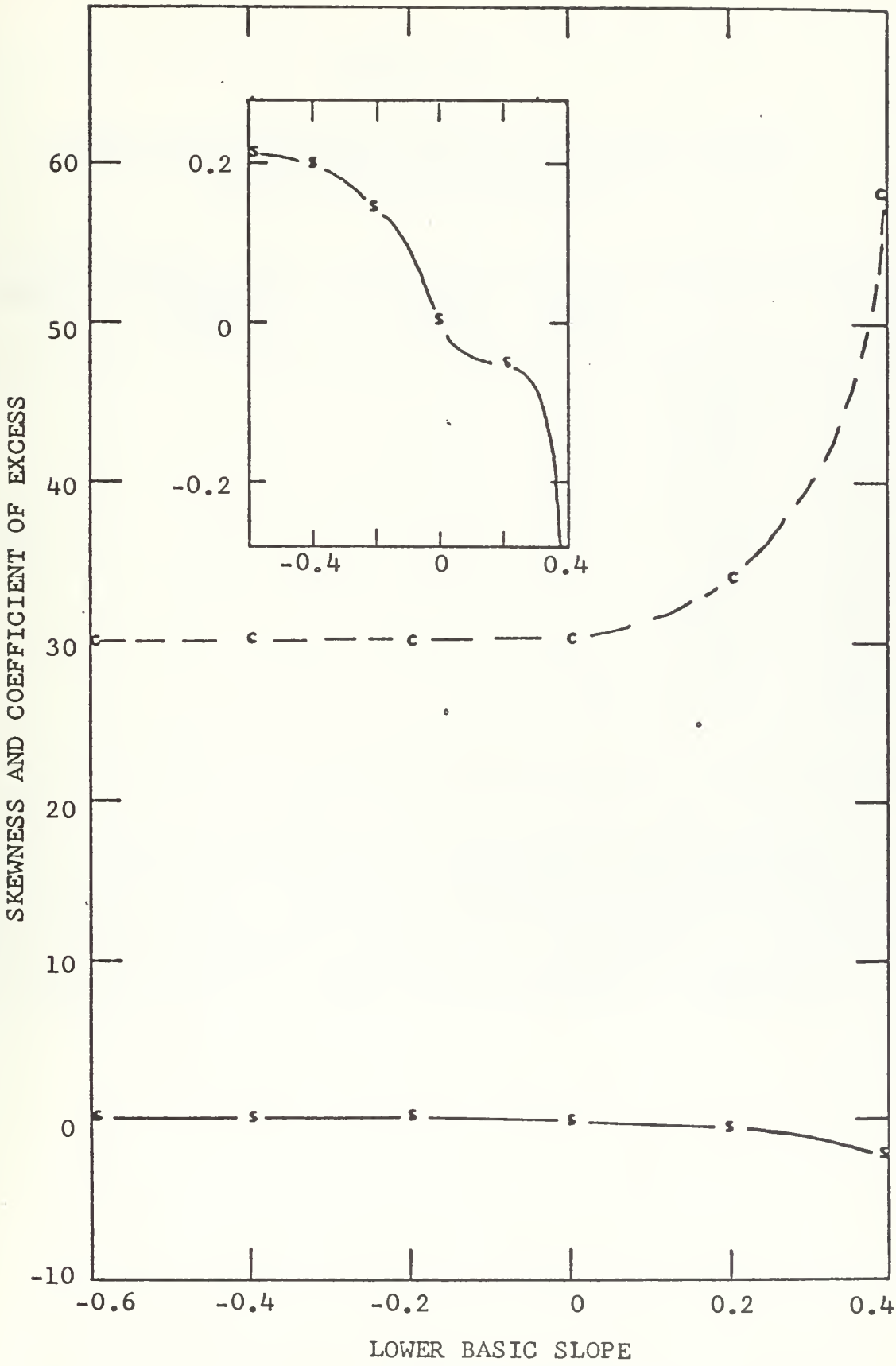


FIGURE 16: VARIATION OF COMPLEX RAMP SIGNAL WITH LOWER BASIC SLOPE (PERIOD = 800, UPPER BASIC SLOPE = 0.8, RAMP WIDTH = 40)

TABLE XII.

VARIATION OF DIFFERENTIATED COMPLEX RAMP SIGNAL WITH RAMP WIDTH (FIGURE 17)

PERIOD	UPPER BASIC SLOPE	LOWER BASIC SLOPE	RAMP WIDTH	S.	C.E.
			40	0.201	30.2
			50	0.145	23.8
			60	0.111	19.5
800	0.8	-0.4	70	0.089	16.3
			80	0.073	14.0
			90	0.061	12.1
			100	0.052	10.6

The effect of varying the ramp width has much the same effect as varying the period. Decreasing the ramp width causes s and c.e. to increase; likewise an increase in period has similar results. These two adjustments however do not produce equal changes in s and c.e. For example, in TABLE IX there is a signal with skewness of 0.145 and a c.e. of 14.3, while from TABLE XII a signal with skewness of 0.145 has a c.e. of 23.8.

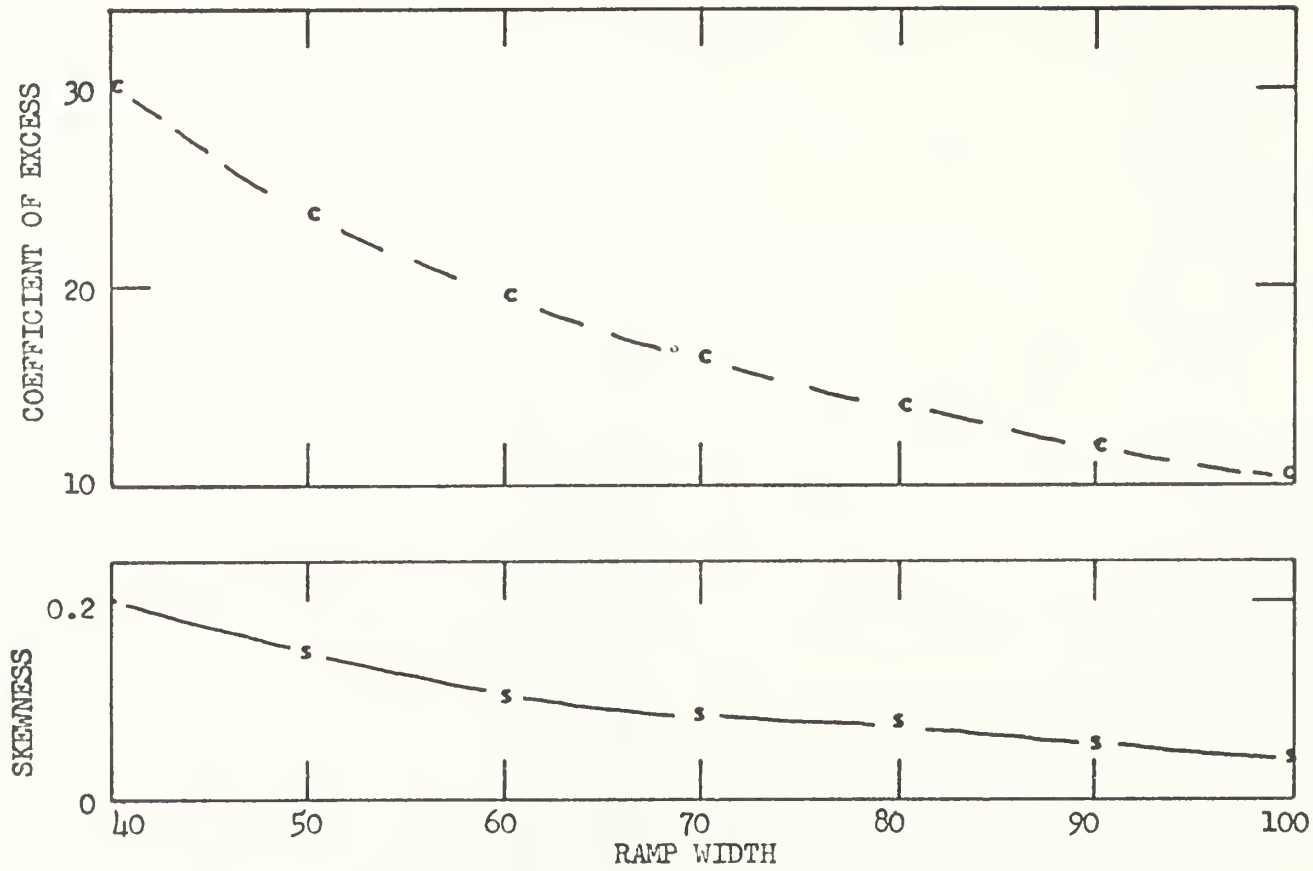


FIGURE 17: VARIATION OF COMPLEX RAMP SIGNAL WITH RAMP WIDTH
(PERIOD = 800, UPPER BASIC SLOPE = 0.8, LOWER BASIC SLOPE = -0.4)

TABLE XIII.

VARIATION OF DIFFERENTIATED COMPLEX RAMP SIGNAL WITH PERIOD AND RAMP WIDTH

PERIOD	UPPER BASIC SLOPE	LOWER BASIC SLOPE	RAMP WIDTH	S.	C.E.
200			10	0.702	28.1
400			20	0.389	30.3
800	0.8	-0.4	40	0.201	30.2
1600			80	0.099	28.5
3200			160	0.047	24.8

TABLE XIII is listed for the information of the reader and as an aid to those who might want to model temperature signals. In each successive entry in TABLE XIII the period and ramp width have been doubled. As previously noted, this has the effect of doubling the frequency of the internal teepees. Also, it is a means of changing the skewness while keeping the c.e. relatively constant.

The preceding tables have not been an attempt to list all the variations possible with the different models, but to examine how various parameters affect the models and to determine which model, if any, is the best representation of atmospheric temperature signals. As previously noted, the complex ramp signal was selected as the best representation. Obviously there exists an infinite number of possible variations and given the actual values of a signal together with the previous tables one should be able to model most of the atmospheric temperature signals encountered in an unstable atmosphere.

The complex ramp provides a coarse and a fine "tuning" mechanism for the model. The ramp width and/or the period can be adjusted to the desired c.e. value with an s value near that desired and then the skewness tuned by adjusting the upper basic slope while the coefficient of excess remains constant. Additionally, the model of the differentiated complex ramp (Figure 6) is remarkably similar to the actual differentiated signal (Figure 1).

V. CONCLUSIONS

The results of this study indicate successful accomplishment of the objective; which was to model a temperature signal from its statistical parameters, skewness, and coefficient of excess. Furthermore, additional insight was gained into the actual structure of temperature signals.

Although the study was not exhaustive it does indicate that one cannot attribute the observed values of skewness and coefficient of excess in the differentiated temperature signal entirely to the external dimensions and frequency of the ramps. Instead one must look at the internal structure of the ramp itself. The ramp is composed of a great many fluctuating high frequency saw-teeth which gradually increase in amplitude giving an overall impression of a relatively gradual rising ramp. The fluctuations are presumably due to mixing or entrainment by the diffuse leading edge of the manifesting plume. The saw-teeth actually extend below the ambient temperature level. This is not readily apparent when examining temperature strip charts but can be attributed to the mechanical response of the recorder and/or sensing system. The internal saw-teeth cause the variation in skewness while the width or frequency of the entire ramp causes variation in c.e. Therefore, given the skewness and coefficient of excess of a temperature signal, a model can be constructed with the exact statistics of the original signal.

VI. RECOMMENDATIONS FOR FURTHER STUDY

A natural extension of this thesis would be an attempt to model actual signals. This would probably require not only an examination of strip chart recordings but also an investigation of the signal's digital representation.

While the asymmetrical ramp signal proved unsatisfactory as a temperature model, in an extreme variation it's statistics were remarkably similar to those of a velocity signal. When the back slope width was only slightly smaller than half the entire ramp width a small negative skewness and a c.e. of near 20 was noted. Several of these results are listed in TABLE XIII. Except for a shape that more resembles a teepee than a ramp, this signal should behave exactly like the previously noted asymmetrical ramp signal. An inspection of a velocity signal indicates that this teepee-like representation is not a bad resemblance. However, it should also be noted that the same results can be achieved with a complex ramp signal whose lower basic slope is greater than zero but necessarily less than the upper basic slope (TABLE XI). Perhaps a more accurate model would be a combination of the two, where high frequency fluctuations are inscribed between two asymmetrical ramps similar to those noted above such that the ramps have the same widths but different heights, i.e., front slopes and back slopes.

If this model proved successful it would hopefully inherit the characteristic of the complex ramp whereby the skewness and c.e. could be adjusted independently.

TABLE XIV.

VARIATION OF A DIFFERENTIATED VELOCITY SIGNAL WITH RAMP WIDTH

PERIOD	BACK SLOPE	FRONT SLOPE	RAMP WIDTH	BACK SLOPE WIDTH	S.	C.E.
100	-1.5	1.5	4	2.0	0.0	22.0
		1.0	5		-1.53	20.3
		0.75	6		-2.89	22.0
		0.60	7		-3.59	24.1

```
THIS PROGRAM COMPUTES THE SKEWNESS (SKEW) AND COEFFICIENT
OF EXCESS (CE) FOR A COMPLEX RAMP SIGNAL WITH A PERIOD OF
800, AN UPPER BASIC SLOPE OF 0.8, A LOWER BASIC SLOPE OF
-0.4 AND A RAMP WIDTH OF 40.  PARAMETERS BOXED WITH *'S ARE
THE VARIABLES OF THE SIGNAL.  A DO LOOP INSERTED BEFORE
STATEMENT 5 AND LOOPED THROUGH STATEMENT 90 WILL ALLOW ONE
OR MORE OF THE VARIABLES TO BE INCREMENTED.

INITIALIZE DATA

      REAL*4 LSLOPE
      DIMENSION X(10000)
    5 DO 10 I=1,10000
   10 X(I)=0.0
      NO=10000
      M=1
      CODE=10**10
      ***********************
      * INT=800             *
      * USLOPE=0.8          *
      * LSLOPE=-0.4         *
      * WIDTH=40            *
      ***********************
      IND=0
      N1=2
      N2=WIDTH/2

COMPUTE COMPLEX SIGNAL

      DO 50 K=1,10000

COMPUTE POSITIVE SLOPES

      X(1+IND)=2.*USLOPE
      DO 25 J=N1,N2
   25 X(2*J-1+IND)=2.*J*USLOPE-(2.*J-1)*LSLOPE

COMPUTE NEGATIVE SLOPES

      N3=N2-1
      X(2+IND)=3.*LSLOPE-2.*USLOPE
      DO 35 J=N1,N3
   35 X(2*J+IND)=(2.*J+1)*LSLOPE-2.*J*USLOPE
      X(2*N2+IND)=-2.*N2*USLOPE
      IND=IND+INT

CHECK IF SIGNAL ARRAY IS FILLED

      IF(2*N2+IND.GT.10000) GO TO 75
   50 CONTINUE

   75 CALL MISR(NO,M,X,CODE,XBAR,STD,SKEW,CE,R,N,A,B,S,IER)
   80 WRITE (6,200) INT,USLOPE,LSLOPE,WIDTH,SKEW,CE
   85 CONTINUE
   90 WRITE (6,300) X
  200 FORMAT('0','INT=',I5,2X,'USLOPE=',F7.3,2X,'LSLOPE=',
     1F7.3,2X,'WIDTH=',F5.1,2X,'SKEW=',F8.3,2X,'CE=',F8.3,/)
  300 FORMAT (1X,'DATA SIGNAL FOLLOWS',/,100(10F10.3/))
      STOP
      END
```

```
C                                                                       MISR  10
C     ..................................................................MISR  20
C                                                                       MISR  30
C        SUBROUTINE MISR                                                MISR  40
C                                                                       MISR  50
C        PURPOSE                                                        MISR  60
C           COMPUTE MEANS, STANDARD DEVIATIONS, SKEWNESS AND KURTOSIS,  MISR  70
C           CORRELATION COEFFICIENTS, REGRESSION COEFFICIENTS, AND      MISR  80
C           STANDARD ERRORS OF REGRESSION COEFFICIENTS WHEN THERE ARE   MISR  90
C           MISSING DATA POINTS.  THE USER IDENTIFIES THE MISSING DATA  MISR 100
C           BY MEANS OF A NUMERIC CODE.  THOSE VALUES HAVING THIS CODE  MISR 110
C           ARE SKIPPED IN COMPUTING THE STATISTICS.  IN THE CASE OF THEMISR 120
C           CORRELATION COEFFICIENTS, ANY PAIR OF VALUES ARE SKIPPED IF MISR 130
C           EITHER ONE OF THEM ARE MISSING.                             MISR 140
C                                                                       MISR 150
C        USAGE                                                          MISR 160
C           CALL MISR (NO,M,X,CODE,XBAR,STD,SKEW,CURT,R,N,A,B,S,IER)    MISR 170
C                                                                       MISR 180
C        DESCRIPTION OF PARAMETERS                                      MISR 190
C           NO    - NUMBER OF OBSERVATIONS                              MISR 200
C           M     - NUMBER OF VARIABLES                                 MISR 210
C           X     - INPUT DATA MATRIX OF SIZE NO X M.                   MISR 220
C           CODE  - INPUT VECTOR OF LENGTH M, WHICH CONTAINS A NUMERIC  MISR 230
C                   MISSING DATA CODE FOR EACH VARIABLE. ANY OBSERVATION MISR 240
C                   FOR A GIVEN VARIABLE HAVING A VALUE EQUAL TO THE CODEMISR 250
C                   WILL BE DROPPED FOR THE COMPUTATIONS.               MISR 260
C           XBAR  - OUTPUT VECTOR OF LENGTH M CONTAINING MEANS          MISR 270
C           STD   - OUTPUT VECTOR OF LENGTH M CONTAINING STANDARD DEVI- MISR 280
C                   ATIONS                                              MISR 290
C           SKEW  - OUTPUT VECTOR OF LENGTH M CONTAINING SKEWNESS       MISR 300
C           CURT  - OUTPUT VECTOR OF LENGTH M CONTAINING KURTOSIS       MISR 310
C           R     - OUTPUT MATRIX OF PRODUCT-MOMENT CORRELATION         MISR 320
C                   COEFFICIENTS.  THIS WILL BE THE UPPER TRIANGULAR     MISR 330
C                   MATRIX ONLY, SINCE THE M X M MATRIX OF COEFFICIENTS  MISR 340
C                   IS SYMMETRIC. (STORAGE MODE 1)                      MISR 350
C           N     - OUTPUT MATRIX OF NUMBER OF PAIRS OF OBSERVATIONS USEDMISR 360
C                   IN COMPUTING THE CORRELATION COEFFICIENTS.  ONLY THE MISR 370
C                   UPPER TRIANGULAR PORTION OF THE MATRIX IS GIVEN.     MISR 380
C                   (STORAGE MODE 1)                                    MISR 390
C           A     - OUTPUT MATRIX (M BY M)  CONTAINING INTERCEPTS OF    MISR 400
C                   REGRESSION LINES (A) OF THE FORM Y=A+BX.  THE FIRST  MISR 410
C                   SUBSCRIPT OF THIS MATRIX REFERS TO THE INDEPENDENT   MISR 420
C                   VARIABLE AND THE SECOND TO THE DEPENDENT VARIABLE.   MISR 430
C                   FOR EXAMPLE, A(1,3) CONTAINS THE INTERCEPT OF THE    MISR 440
C                   REGRESSION LINE FOR TWO VARIABLES WHERE VARIABLE 1   MISR 450
C                   IS INDEPENDENT AND VARIABLE 3 IS DEPENDENT.  NOTE    MISR 460
C                   THAT MATRIX A IS STORED IN A VECTOR FORM.            MISR 470
C           B     - OUTPUT MATRIX (M BY M)  CONTAINING REGRESSION       MISR 480
```

```
C                COEFFICIENTS (B) CORRESPONDING TO THE VALUES OF        MISR 490
C                INTERCEPTS CONTAINED IN THE OUTPUT MATRIX A.           MISR 500
C          S     - OUTPUT MATRIX (M BY M) CONTAINING STANDARD ERRORS     MISR 510
C                OF REGRESSION COEFFICIENTS CORRESPONDING TO THE        MISR 520
C                COEFFICIENTS CONTAINED IN THE OUTPUT MATRIX B.         MISR 530
C          IER   - 0, NO ERROR.                                         MISR 540
C                1, IF NUMBER OF NON-MISSING DATA ELEMENTS FOR J-TH     MISR 550
C                   VARIABLE IS TWO OR LESS.  IN THIS CASE, STD(J),     MISR 560
C                   SKEW(J), AND CURT(J) ARE SET TO 10**75.  ALL        MISR 570
C                   VALUES OF R, A, B, AND S RELATED TO THIS VARIABLE   MISR 580
C                   ARE ALSO SET TO 10**75.                             MISR 590
C                2, IF VARIANCE OF J-TH VARIABLE IS LESS THAN           MISR 600
C                   10**(-20).  IN THIS CASE, STD(J), SKEW(J), AND      MISR 610
C                   CURT(J) ARE SET TO 10**75.  ALL VALUES OF R, A,     MISR 620
C                   B, AND S RELATED TO THIS VARIABLE ARE ALSO SET TO   MISR 630
C                   10**75.                                             MISR 640
C                                                                       MISR 650
C     REMARKS                                                           MISR 660
C        THIS SUBROUTINE CANNOT DISTINGUISH A BLANK AND A ZERO.         MISR 670
C        THEREFORE, IF A BLANK IS SPECIFIED AS A MISSING DATA CODE INMISR 680
C        INPUT CARDS, IT WILL BE TREATED AS 0 (ZERO).                   MISR 690
C                                                                       MISR 700
C     SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED                     MISR 710
C        NONE                                                           MISR 720
C                                                                       MISR 730
C     METHOD                                                            MISR 740
C        LEAST SQUARES REGRESSION LINES AND PRODUCT-MOMENT CORRE-       MISR 750
C        LATION COEFFICIENTS ARE COMPUTED.                              MISR 760
C                                                                       MISR 770
C     ..................................................................MISR 780
C                                                                       MISR 790

      SUBROUTINE MISR (NO,M,X,CODE,XBAR,STD,SKEW,CURT,R,N,A,B,S,IER)    MISR 800
C                                                                       MISR 810
      DIMENSION X(1),CODE(1),XBAR(1),STD(1),SKEW(1),CURT(1),R(1),N(1)   MISR 820
      DIMENSION A(1),B(1),S(1)                                          MISR 830
C                                                                       MISR 840
CC    COMPUTE MEANS                                                     MISR 850
C                                                                       MISR 860
      IER=0                                                             MISR 870
      L=0                                                               MISR 880
      DO 20 J=1,M                                                       MISR 890
      FN=0.0                                                            MISR 900
      XBAR(J)=0.0                                                       MISR 910
      DO 15 I=1,NO                                                      MISR 920
      L=L+1                                                             MISR 930
      IF(X(L)-CODE(J)) 12, 15, 12                                       MISR 940
```

```
   12 FN=FN+1.0                                                          MISR 950
      XBAR(J)=XBAR(J)+X(L)                                               MISR 960
   15 CONTINUE                                                           MISR 970
      IF(FN) 16, 16, 17                                                  MISR 980
   16 XBAR(J)=0.0                                                        MISR 990
      GO TO 20                                                           MISR1000
   17 XBAR(J)=XBAR(J)/FN                                                 MISR1010
   20 CONTINUE                                                           MISR1020
C                                                                        MISR1030
CC       SET-UP WORK AREAS AND TEST WHETHER DATA IS MISSING              MISR1040
C                                                                        MISR1050
      L=0                                                                MISR1060
      DO 55 J=1,M                                                        MISR1070
      LJJ=NO*(J-1)                                                       MISR1080
      SKEW(J)=0.0                                                        MISR1090
      CURT(J)=0.0                                                        MISR1100
      KI=M*(J-1)                                                         MISR1110
      KJ=J-M                                                             MISR1120
      DO 54 I=1,J                                                        MISR1130
      KI=KI+1                                                            MISR1140
      KJ=KJ+M                                                            MISR1150
      SUMX=0.0                                                           MISR1160
      SUMY=0.0                                                           MISR1170
      TI=0.0                                                             MISR1180
      TJ=0.0                                                             MISR1190
      TII=0.0                                                            MISR1200
      TJJ=0.0                                                            MISR1210
      TIJ=0.0                                                            MISR1220
      NIJ=0                                                              MISR1230
      LI=NO*(I-1)                                                        MISR1240
      LJ=LJJ                                                             MISR1250
      L=L+1                                                              MISR1260
      DO 38 K=1,NC                                                       MISR1270
      LI=LI+1                                                            MISR1280
      LJ=LJ+1                                                            MISR1290
      IF(X(LI)-CODE(I)) 30, 38, 30                                       MISR1300
   30 IF(X(LJ)-CODE(J)) 35, 38, 35                                       MISR1310
C                                                                        MISR1320
CC       BOTH DATA ARE PRESENT                                           MISR1330
C                                                                        MISR1340
   35 XX=X(LI)-XBAR(I)                                                   MISR1350
      YY=X(LJ)-XBAR(J)                                                   MISR1360
      TI=TI+XX                                                           MISR1370
      TII=TII+XX** 2                                                     MISR1380
      TJ=TJ+YY                                                           MISR1390
      TJJ=TJJ+YY** 2                                                     MISR1400
      TIJ=TIJ+XX*YY                                                      MISR1410
      NIJ=NIJ+1                                                          MISR1420
```

```
      SUMX=SUMX+X(LI)                                                    MISR1430
      SUMY=SUMY+X(LJ)                                                    MISR1440
      IF(I-J) 38, 37, 37                                                 MISR1450
   37 SKEW(J)=SKEW(J)+YY**3                                              MISR1460
      CURT(J)=CURT(J)+YY**4                                              MISR1470
   38 CONTINUE                                                           MISR1480
C                                                                        MISR1490
CC         COMPUTE SUM OF CROSS-PRODUCTS OF DEVIATIONS                   MISR1500
C                                                                        MISR1510
      IF(NIJ) 40, 40, 39                                                 MISR1520
   39 FN=NIJ                                                             MISR1530
      R(L)=TIJ-TI*TJ/FN                                                  MISR1540
      N(L)=NIJ                                                           MISR1550
      TII=TII-TI*TI/FN                                                   MISR1560
      TJJ=TJJ-TJ*TJ/FN                                                   MISR1570
C                                                                        MISR1580
CC         COMPUTE STANDARD DEVIATION, SKEWNESS, AND KURTOSIS            MISR1590
C                                                                        MISR1600
   40 IF(I-J) 47, 41, 47                                                 MISR1610
   41 IF(NIJ-2) 42,42,43                                                 MISR1620
   42 IER=1                                                              MISR1630
      R(L)=1.0E75                                                        MISR1640
      A(KI)=1.0E75                                                       MISR1650
      B(KI)=1.0E75                                                       MISR1660
      S(KI)=1.0E75                                                       MISR1670
      GO TO 45                                                           MISR1680
C                                                                        MISR1690
   43 STD(J)=R(L)                                                        MISR1700
      R(L)=1.0                                                           MISR1710
      A(KI)=0.0                                                          MISR1720
      B(KI)=1.0                                                          MISR1730
      S(KI)=0.0                                                          MISR1740
C                                                                        MISR1750
      IF(STD(J)-(1.0E-20)) 44,44,46                                      MISR1760
   44 IER=2                                                              MISR1770
   45 STD(J)=1.0E75                                                      MISR1780
      SKEW(J)=1.0E75                                                     MISR1790
      CURT(J)=1.0E75                                                     MISR1800
      GO TO 55                                                           MISR1810
C                                                                        MISR1820
   46 WORK=STD(J)/FN                                                     MISR1830
      SKEW(J)=(SKEW(J)/FN)/(WORK*SQRT(WORK))                             MISR1840
      CURT(J)=((CURT(J)/FN)/WORK**2)-3.0                                 MISR1850
      STD(J)=SQRT(STD(J)/(FN-1.0))                                       MISR1860
      GO TO 55                                                           MISR1870
C                                                                        MISR1880
CC         COMPUTE REGRESSION COEFFICIENTS                               MISR1890
C                                                                        MISR1900
```

```
   47 IF(NIJ-2) 48,48,50                                                MISR1910
   48 IER=1                                                             MISR1920
   49 R(L)=1.0E75                                                       MISR1930
      A(KI)=1.0E75                                                      MISR1940
      B(KI)=1.0E75                                                      MISR1950
      S(KI)=1.0E75                                                      MISR1960
      A(KJ)=1.0E75                                                      MISR1970
      B(KJ)=1.0E75                                                      MISR1980
      S(KJ)=1.0E75                                                      MISR1990
      GO TO 54                                                          MISR2000
C                                                                       MISR2010
   50 IF(TII-(1.0E-20)) 52,52,51                                        MISR2020
   51 IF(TJJ-(1.0E-20)) 52,52,53                                        MISR2030
   52 IER=2                                                             MISR2040
      GO TO 49                                                          MISR2050
C                                                                       MISR2060
   53 SUMX=SUMX/FN                                                      MISR2070
      SUMY=SUMY/FN                                                      MISR2080
      B(KI)=R(L)/TII                                                    MISR2090
      A(KI)=SUMY-B(KI)*SUMX                                             MISR2100
      B(KJ)=R(L)/TJJ                                                    MISR2110
      A(KJ)=SUMX-B(KJ)*SUMY                                             MISR2120
C                                                                       MISR2130
C        COMPUTE CORRELATION COEFFICIENTS                               MISR2140
C                                                                       MISR2150
      R(L)=R(L)/(SQRT(TII)*SQRT(TJJ))                                   MISR2160
C                                                                       MISR2170
C        COMPUTE STANDARD ERRORS OF REGRESSION COEFFICIENTS             MISR2180
C                                                                       MISR2190
      RR=R(L)**2                                                        MISR2200
      SUMX=(TJJ-TJJ*RR)/(FN-2)                                          MISR2210
      S(KI)=SQRT(SUMX/TII)                                              MISR2220
      SUMY=(TII-TII*RR)/(FN-2)                                          MISR2230
      S(KJ)=SQRT(SUMY/TJJ)                                              MISR2240
C                                                                       MISR2250
   54 CONTINUE                                                          MISR2260
   55 CONTINUE                                                          MISR2270
C                                                                       MISR2280
      RETURN                                                            MISR2290
      END                                                               MISR2300
```

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13. ABSTRACT

The "ramp" is an often observed feature in temperature fluctuations during unstable atmospheric conditions. It is characterized by a gradual increase in temperature followed by a sudden drop to an ambient level. This ramp clearly distinguishes temperature signals from other turbulence signals such as velocity. Three different ramp-type atmospheric temperature fluctuations and their derivatives are constructed and statistically examined for the parameters skewness and coefficient of excess. These statistical values are compared with values obtained from actual signals. The "complex ramp signal" was found to represent these quite well. Skewness and coefficient of excess for this signal could be altered almost independently of each other. The complex ramp is constructed by inscribing nearly symmetrical consecutive triangles within two envelope rays of constant but different slopes such that the two envelope rays approximate a ramp function.

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